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Barlian Dwinagara, Pawitra Wijaya, Oktarian W. Lusantono, et al.

Permeability Value Estimation Based on Rock Mass Rating

Barlian Dwinagara[1,a)], Pawitra Wijaya[1,b)], Oktarian W. Lusantono[1,c)], Istifari Husna Rekinagara[2,d)], and Shofa Rijalul Haq[2,e)]

[1]*Department of Mining Engineering, UPN "Veteran" Yogyakarta – Jl. Padjajaran (SWK 104), Condongcatur Sleman, Yogyakarta, Indonesia*

[2]*PT Studio Mineral Batubara, Mining Consultant – Jl. Gang Mulia VI No 67, Ngaglik, Sleman, Yogyakarta, Indonesia*

[a)]Corresponding author: barliandn@upnyk.ac.id, [b)]pawitra.rara@gmail.com, [c)]oktarian.lusantono@upnyk.ac.id, [d)]istifari@mcsindonesia.co.id, [e)]shofa@mcsindonesia.co.id

Abstract. Groundwater flow in an underground mining operation was affected by rock conditions and distributed through interconnected fractures. This study investigated underground groundwater leakage in a gold mining operation through permeability parameter. Groundwater inflow was obtained from water-balance analysis around 16.37 L/s. Since permeability tests sample was difficult to obtain, permeability value was estimated using Snow equations methods. The analysis had taken place in 4 different areas in the mine consisted of different rock mass classification zone. Rock Mass Rating (RMR) selected as rock mass classification system due to aperture parameter was incorporated in the classification system. The analysis was conducted through linear-regression analysis. The coefficient of correlation (R^2) between RMR and permeability value was 0.82 generally. In conclusion, RMR may provide preliminary permeability value.

Keywords: *Underground mining, Permeability, Rock Mass Rating*

INTRODUCTION

PT Cibaliung Sumberdaya (PT. CSD) is a gold ore (Au) mine in the Cikoneng, Cibitung and Rorakadal blocks using the cut & fill method. In carrying out mining activities, the obstacles often faced are (i) the occurrence of collisions followed by subsidence of the soil surface, (ii) groundwater leakage, and (iii) groundwater seepage at some underground mine levels. Water pressures (i.e., pore water pressure and water pressure along the joints) are critical along with water sensitivity of the rock material. Permeability of the intact rock and the rock mass alters due to the presence and frequency of discontinuities. Discontinuity conditions (i.e., persistence, tightness, aperture, roughness, infill type, filling thickness of the discontinuities) govern the water flow rate through a rock mass and affecting rock mass strength. Moreover, insitu stress influences water flow [1].

According to previous research on water balance in Cibitung Block [2], more than 50% of water entering the opening of underground mine came from groundwater flows. The existence of groundwater flow was identified as predominantly influenced by the fracture aquifer [3]. Fracture aquifer consists of fractures interconnected in rocks and can be identified from the shape or dimensions of the fracture (e.g., aperture, length, and depth) and the location of fractures (e.g., orientation, space and fracture walls) [4]. If a rock has primary permeability, then the fracture of this rock will increase the value of the rock's permeability. Then, it is called the secondary permeability of the rock illustrating that the permeability of the rock is closely related to the rock mass quality index.

Therefore, conducting a research on the analysis and identification of secondary permeability as one of the important factors is crucial to determine the quality of rock mass through the RMR (Rock Mass Rating). The purpose of this research is to identify the secondary permeability to obtain RMR by considering the opening structures in underground mine in Cibitung block. The results of this study are useful as a reference for determining secondary permeability based on specific gravity and rock characteristics to consider the rock mass quality index on the underground mine at PT CSD.

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LITERATURE REVIEW

Water Flow in Rock

High frequency fracturing media usually creates problems for rock engineering activities such as excavating tunnels, slopes, and building dams [5]. Apart from being a weak area in rocks, fractures in rocks drained groundwater also become the main problem in underground activities. This problem caused by the stability of the rock depends on the shear strength is influenced by the pore pressure in the fracture medium.

Furthermore, a stable structural state in dry conditions will become unstable when the water content increases. In tunnels or openings, knowing the condition of groundwater velocity in liters/meter for every 10 meters of excavation is mandatory. The general condition of groundwater can be expressed as dry, humid, wet, dripping, and flowing [6]. In addition, permeability is one of the parameters for determining flow in rock [7].

Rock Permeability

Basic parameter determining groundwater flow and water pressure distribution in geological approach is the hydraulic conductivity. Previous researches [8] identified that hydraulic conductivity parameter is related to the flow rate of water through the pressure gradient material. Permeability is often known as hydraulic conductivity. At primary permeability, fluid flows through rock pores. The permeability value affects the ability of water to flow proportionally. If the permeability value is higher, the ability of water to flow will increase [9].

The magnitude of permeability value is influenced by several factors including lithological conditions. The lithology with solid characteristics such as volcanic rock has a low primary permeability value because these rocks tend to have no gaps between the grains. Meanwhile, lithology such as sandstones has a large primary permeability value because sandstones tend to have many gaps between grains [10]. This experiment conducted by soil flow and the notion of permeability, known as Darcy's law:

$$Q = -KA\frac{dh}{dl} \tag{1}$$

where Q (m^3/s) is the amount of water flowing through a unit area (A in m^2) with a hydraulic gradient of dh / dl. The proportionality factor K (m/s) is called the hydraulic conductivity. Discontinuous field conditions in the expanded rock mass (e.g., opening) cause turbulent groundwater flow in the rock mass. Therefore, Darcy's law can no longer be applied.

Rock Mass Permeability

Previous researchers [11]; [12] linked the rock mass permeability with the rock mass quality index such as Rock Quality Determination (RQD) and RMR. The permeability coefficient decreases with the increasing RQD [12]. Meanwhile, research at area consisting of monzonite granite, monzonite quartz, and syenite quartz in East Shandong Province, China showed a relationship between the K and RQD field rock mass permeability coefficients with different determination coefficients **(FIGURE 1)** .

$$\log K = 1.689 - 0{,}0236 RQD,\ r^2 = 0{,}78 \tag{2}$$

where,

$Log\ K$ = coefficient permeability (cm/day)

RQD = *Rock Quality Designation*

r^2 = coefficient determination

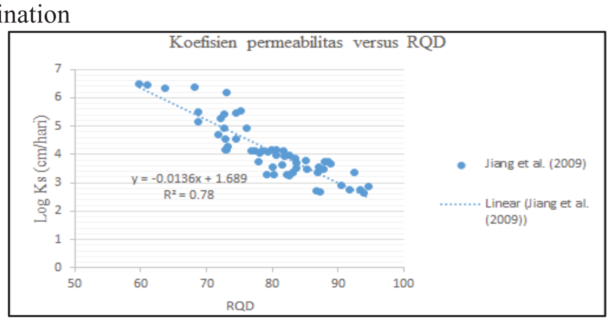

FIGURE 1. Relationship between secondary permeability coefficient and RQD [12]

FIGURE 2 illustrates the efficient permeability of packer tests as opposed to the RMR for the Cambrian sandstone mass in Central Jordan. The following relationship between the permeability coefficient K and RMR can be derived using regression analysis; logK = 6.749 - 0,0835RMR, r^2 = 0,74 [11].

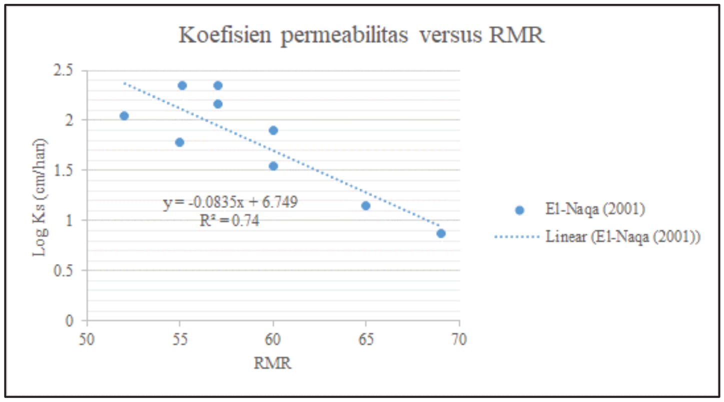

FIGURE 2. Secondary permeability coefficient versus RMR [11]

Geology of the Study Area

Study area is on PT CSD concession in the southwestern tip of Java Island. Administratively, it is located in three sub-districts (Cimanggu, Cibaliung, and Cibitung District), of Pandeglang Regency, Banten Province **(FIGURE 3)** . PT CSD is a hilly area with an altitude between 300 and 620 meter above sea level (masl) with a slope of 7% - 20%. The highest hills are located on the west of Cibaliung exploration concession area, namely Mount Honje with an altitude of 620 masl and included in the Ujung Kulon National Park area. The main rivers in this area are the Citeluk, Cikoneng, and Cibeber river flowing from north to south and generally form a rectangular flow pattern. Mining Business Permit Area of PT CSD covers an area of 7,811 ha, consisted of an Exploration IUP of 6,471 ha and an exploitation concession area of 1,340 ha (**FIGURE 4**). Ore deposits in the Cikoneng - Cibitung exploitation concession area were formed in the dilatational complex area which coincides with the sigmoid bends structural pattern in the intersection area between the northwest-southeast trending fault system, north-west-south-southeast, and northeast-southwest. Therefore, the vertical mineralization zone was formed longer than the lateral one. This is the combination result of dilatation effect from three main fault sets. In terms of geological structure, the gold prospect in the Cibaliung exploration concession area is located in a structural corridor trending northwest of the Southeast with a width of 3.5 km and a length of 6 km. Two structures that traverse north-northwest and south-southeast, which are rich in gold reserves are the Cikoneng vein on the north and the Cibitung vein on the south. The veins that contain gold each have a thickness of 1 – 10 m, a length of 140 – 200 m, with a depth of more than 300 m and still going down.

FIGURE 3. Location map of study area (Feasibility Study of PT CSD)

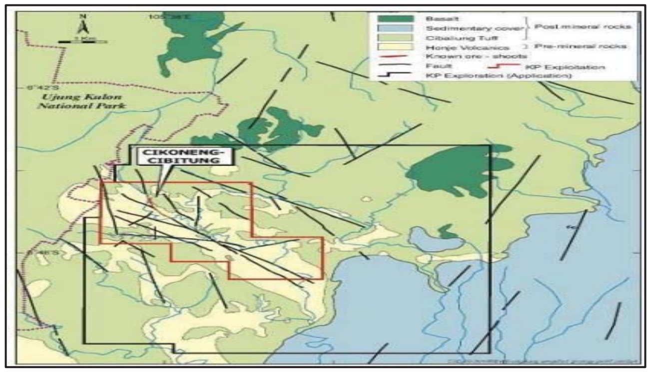

FIGURE 4. Mining business permit area of PT CSD (Geotechnical Department of Mining PT CSD)

The oldest pre-mineralized rock (host) at PT CSD is a thick layer of rock basaltic to volcanic andesitic (ANDS), volcanic breccias (BRAN), polymict breccias (PLBX), and heterolithic milled matrix breccia or called monomict breccias (MNBX). Tuff is generally several meters thick in the mine area, but can also be up to 30 m. A thin layer of unconsolidated colluvium/alluvium consisting of pre-mineral rock and vein material quartz is generally at the base of the tuff. Heterolithic milled matrix breccia (HMMB), also known as diatreme, is known to be associated with andesite to diorite intrusion. These rock units are generally 1 – 120 m wide, 20 – 120 m long with a depth of 20 – <200 m. These breccias consist of angled to rounded fragments of rock prior to mineralization in the powdery volcanic igneous rock matrix. The common fragments are andesite – basalt; fine volcanic-clastic; porphyritic andesite and diorite; and sometimes granodiorite.

HMMB occurs associated with andesite intrusion, formed after intrusion and before the formation of epithermal veins. HMMB can certainly be formed as rock prior to mineralization. On the other hand, it is also a trigger for the formation of epithermal vein mineralization. This is indicated by the finding of fluidized milled data which is rich in pyrite and truncated by quartz veins. Lithological description of PT CSD, especially Cibitung block illustrated in the N4510 cross section **(FIGURE 5)** .

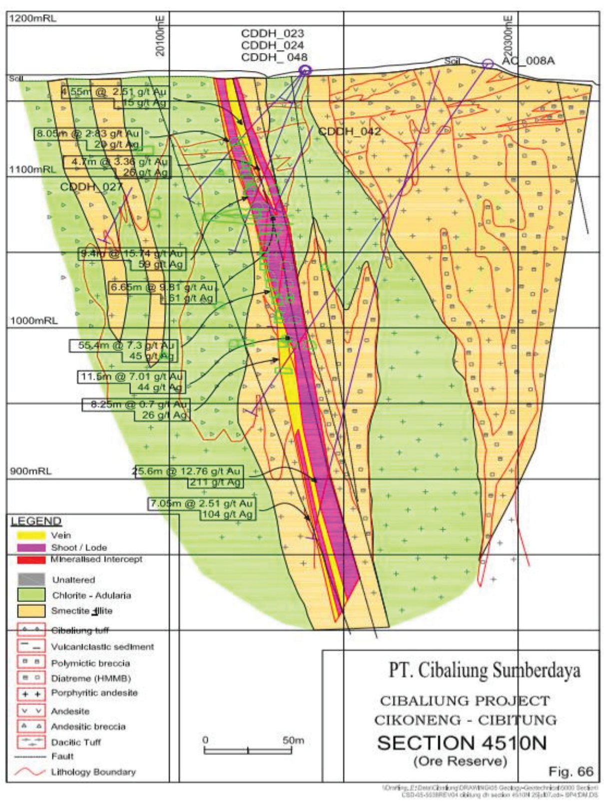

FIGURE 5. Section N4510 Cibitung Block (PT CSD)

In terms of geological structure, the gold prospect in Cibaliung is located in a structural corridor trending West – Northwest with a width of 3.5 km and length of 6 km. Two structures towards the North – Northwest which are rich in gold reserves with a relatively upright position as a quartz vein system, are Cikoneng to the North and Cibitung to the South which is 400 m apart. This reserve has 1 – 10 m thick, 140 – 200 m long, with the depth of 300 m and still going down. Gold and silver ores at Cikoneng-Cibitung occur by several phases of the "low sulfidation adularia-sericite" quartz vein [13] [14] or "epithermal quartz gold-silver vein" [15]; [16], illustrated in **FIGURE 6**.

METHODOLOGY

Permeability values were obtained from each lithology in Cibitung block underground mine, along with the calculation of rock characteristics in the form of openings and fracture spaces based on [17] through geological drill logs. The data needed for this research were primary and secondary data. Primary data were obtained from direct measurements in the form of discharge data, backfill slurry sampling, and core log samples. Secondary data were obtained from laboratories and in the form of permeability test data, topographic maps, geological drill logs, RMR, production activity data, and mine drainage. Both primary and secondary data obtained were then processed and analyzed to produce output in the form of the location of water sources, the distribution of secondary permeability, and the relationship between secondary RMR permeability. This research was carried out at the mine surface and in underground mines. Underground mining research data is limited to the cross sections of N4390, N4450, N4510 **(FIGURE 7).**

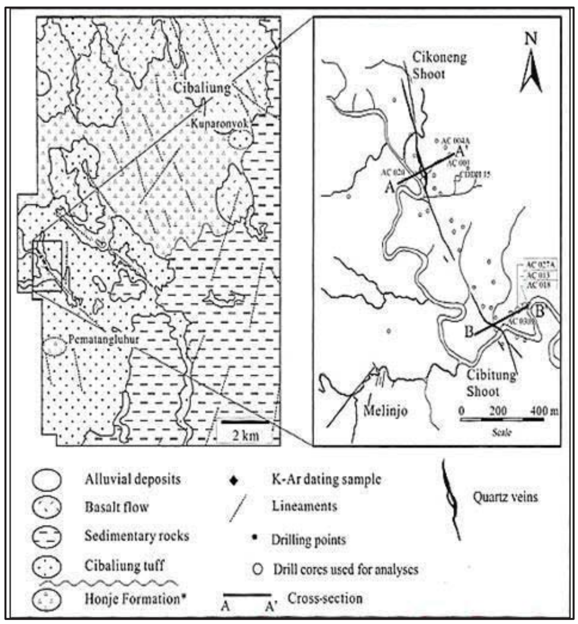

FIGURE 6. Geological map of KP. Exploration and KP. Exploitation (PT CSD, 2009)

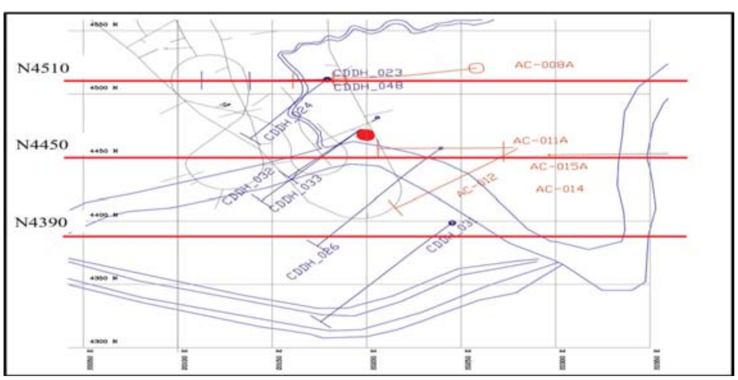

FIGURE 7. Cross section of research area at PT.CSD Cibitung Block

RESULTS AND DISCUSSION

Aperture and Space Calculation on Geological Drill Log Data

TABLE 1 below describes hydrological measurement data, which the mine water balance in the Cibitung block was calculated. The total water in and out of open pit mine was 24.6 L/s. Water in consists of groundwater flow (16.37 L/s), stuffing material (4.51 L/s), drilling activities (2.06 L/s), pipe leaking (1.64 L/s), and concrete support (0.02 L/s). Meanwhile, water out consists of pumping (23.63 L/s) and water for ore and waste hauling (0.98 L/s).

TABLE 1. Cibitung's Block Mine Water Balance

No	Portion	Water source	Discharge (L/second)
1	Water in	Groundwater flow	16.37
2		Stuffing material	4.51
3		Drilling activities	2.06
4		Pipe leaking	1.64
5		Concrete support	0.02
A	**Total of water in to open pit mine**		**24.6**
6	Water out	Pumping	23.63
7		Water for ore and waste hauling	0.98
B	**Total of water out from open pit mine**		**24.6**

Aperture or fracture openings is one of the characteristics in the condition of a discontinuous or discontinuous plane. Aperture and space were calculated through geological drill log data belonging to the PT CSD quality control work unit. Aperture in **TABLE 2** was calculated by adding up the thickness of the infill (column k and o) which indicates the presence of aperture in columns e and h for each lithological difference. Description of number symbols in column e and h is shown in **TABLE 3**. The infill material was dominated with clay. The space in **TABLE 2** can be calculated by adding up the thickness of the structure (column k and o) which indicates the existence of a discontinuous plane in column m. The average thickness of structure opening was 0.87 m ranging from 0.15 – 1.5 m. Description of the number symbol in column m is shown in **TABLE 4**.

TABLE 2. Table of aperture dan space calculation on Drill Log AC-008A

From (m)	To (m)	Lithology	Geomechanical - Structure							Structure			
			Fractures	Infill	Veins	Angle	Infill	Gouge	Angle	From	To	Structure	Angle
a	b	c	d	e	f	g	h	i	j	k	o	m	n
0.00	1.50	1	0		0			0		0	0		
1.50	1.75	1	0		0			0		0	0		
1.75	2.20	1	0		0			0		0	0		
2.20	2.48	1	0		0			0		0	0		
2.48	3.25	10	0		0			0		0.00	0.00		
3.25	4.75	10	0		0			0		0.00	0.00		
4.75	6.25	10	1	4	0			0		4.75	6.25	2	
6.25	7.75	10	0		0			0		0.00	0.00		
7.75	8.85	10	0		0			0		0.00	0.00		
8.85	9.25	10	0		0			0		0.00	0.00		
9.25	10.60	10	0		0			0		0.00	0.00		
10.60	11.55	10	2	4	0			0		10.60	11.55	2	
11.55	12.25	10	2	4	0			0		11.55	12.25	2	
12.25	13.75	10	0		0			0		0.00	0.00		
13.75	15.25	10	0		0			0		0.00	0.00		
15.25	16.75	10	4	4	0			0		15.25	16.75	2	
16.75	18.25	10	0		0			0		0.00	0.00		
18.25	19.30	10	0		0			0		0.00	0.00		
19.30	20.80	10	2	4	0			0		20.20	20.80	2	NA
20.80	22.05	10	1	4	0			0		20.80	21.05	2	NA
22.05	22.75	10	0		0			0		0.00	0.00		
22.75	23.25	10	0		0			0		0.00	0.00		
23.25	24.25	10	1	4	0			0		24.20	24.28	1	NA
24.25	25.75	10	0		2	23	4	0		24.25	25.75	2	
25.75	27.25	10	0		0			0		0.00	0.00		
27.25	28.75	10	2	4	2	13	4	0		27.25	28.75	2	
28.75	29.55	10	1	4	0			0		28.75	29.55	2	
29.55	30.25	9	0		0			0		0.00	0.00		
30.25	31.75	9	0		5	45	2	0		30.35	30.50	2	35

TABLE 3. Table of fracture and vein fill

Comp. Code	Letter code	Description
1	QZ	Quartz
2	CB	Carbonate
3	QC	Quartz – Carbonate
4	CY	Clay
5	QY	Quartz – Clay
6	CC	Carbonate – Clay
7	QX	Quartz Clay - Carbonate

TABLE 4. Table of Structure and Column

Comp. Code	Symbol	Letter Code	Description
1	1	FLT	Faults
2	2	SHR	Shear (Pseude-ductile, Restricted to Clay Rich Rocks)
3	3	HFZ	Highly Fracture Zona (no shearing)
4	4	CNT	Contact (Lithology/ Structural)
5	5	BED	Bedding/Layering/Dominat Vein Banding
6	6	VEN	Quartz Clay - Carbonate

Rock Mass Rating (RMR) Classification Data

Rock sample density measurements are carried out to calculate rock density. Rock samples measured come from exploration cores belonging to the quality control work unit PT CSD. The measurement results are showed in **TABLE 5**. The rock density varied from 1.75 – 3.49 kg/L, while the unit weight ranged from 17.12 – 34.25 N/m^3.

TABLE 5. Table of rock density measurement

Litologi		ρ (Densitas/MassaJenis)	ϒ (BeratJenis)
Deskripsi	Kode	Kg.l^{-1}	N.m^{-3} atau Kg.m^{-2}.s^{-2}
Cibaliung Tuff	TUFF	1.75	17.12
Volcaniclastic Sediment	VCDS	2.94	28.80
Conglomeratic Breccia	CONG	2.31	22.66
Hydrothermal Milled Matrix Bx	HMMB	3.05	29.96
Andesitic Flow	ANDS	2.36	23.19
Porphyritic Andesite	PAND	2.85	27.98
Diorite	DIOR	3.00	29.46
Monomictic Breccia	MNBX	2.48	24.31
Polymictic Breccia	PLBX	2.27	22.28
Dacitic Tuff	DATF	3.49	34.25
Andesitic Breccia	BRAN	2.53	24.83
Soil, Overburden	OVER	2.45	24.03
Basalt Dyke	DBSL	2.45	24.01
Gouge (No Vein material)	GOUG	2.60	25.51
Vein Breccia (Clay Rich)	FTBR	2.28	22.41
Vein Breccia	VNBR	2.48	24.30
Crustiform - Colloform	VEIN	2.43	23.88
Quartz Stocwork	FTVN	2.97	29.10

Rock Mass Rating (RMR) values were obtained from previous research in the same area illustrated in **TABLE 6**. The RMR of rock masses around the study area ranges from 32 to 49. In other words, the rock masses are in class III or fair rock, and class IV or poor rock.

TABLE 6. Table of RMR Value on the Research Location (PT CSD, 2017)

Lokasi	Level	RMR
CBT_996_XC8_STH	179	38
CBT_966_XC9_STH	209	43
CBT_951_XC10_STH	224	45
CBT_1065_XC6_STH	110	40
CBT_956_XC10_ACC	219	42
CBT_936_XC11_STH	239	40
CBT_936_XC11_STH	239	36
CBT_936_XC11_STH	239	39
CBT_936_XC11_STH	239	39
CBT_936_XC11_STH	239	36
CBT_936_XC11_STH	239	45
CBT_936_XC11_NTH	239	38
CBT_936_XC11_NTH	239	49
CBT_936_XC11_NTH	239	34
CBT_936_XC11_NTH	239	35
CBT_936_XC11_NTH	239	44
CBT_936_XC11_NTH	239	35
CBT_936_XC11_NTH	239	39
CBT_936_XC11_NTH	239	41
CBT_936_XC11_NTH	239	38
CBT_936_XC11_NTH	239	32
CBT_936_XC11_NTH	239	40

Secondary Permeability Statistical Analysis

Because of the 66.54% of water sources in the Cibitung Block came from groundwater flow, which was 16.37 L/s. The existence of groundwater flow was identified as predominantly influenced by the fracture aquifer [3]. The value of secondary permeability coefficient or called Log (Ks) was calculated based on the Snow Equation. **TABLE 7** and **FIGURE 8** describe the overall calculation data of secondary permeability in this study normally distributed. Based on log descriptive statistical analysis, the mean and standard deviation of all data were 1.26 and 3.6, respectively.

TABLE 7. Log descriptive statistical analysis (ks) on all data

Parameter	Statistic	Std. Error
Number	244.00	
Mean	3.60	0.08
95% Confidence Interval | Lower Bound	3.44	
For Mean | Upper Bound	3.76	
5% Trimmed Mean	3.57	
Median	3.56	
Variance	1.61	
Std. Deviation	1.26	
Minimum	0.71	
Maximum	8.83	
Range	8.12	
Skewness	0.47	0.15
Kurtosis	1.23	0.31

Based on **TABLE 8**, the results of secondary permeability analysis which are grouped for each level show the presence of water bags which are shown from different color groups. The colors in the table are divided according to its typical [18], where the red color indicates the high permeability to the green color indicates the low permeability. **TABLE 8** shows that there are 4 groups of indications of a water bag, namely above the P130 level, then between the P110 level to the P040 level, then between the P030 level to the P000 level and below the M030 level.

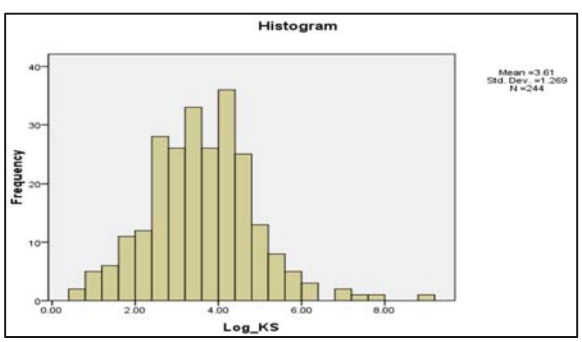

FIGURE 8. Log Histogram (Ks) on all data

TABLE 8. Permeability Analysis based on Stratified Level

Row Level	Lithology								Average
	VNBR	VEIN	GOUG	FTVN	FTBR	PAND	ANDS	BRAN	
P170								2.5	3.2
P160							1.7	3.6	2.9
P150							2.9	2.3	2.6
P140			3.9		2.6	2.6	3.5	3.0	3.4
P130				3.3			2.8	2.8	3.0
P120	3.4					3.1	4.4	3.9	3.6
P110	3.0		3.9		4.7	2.3	4.2	2.7	3.3
P100	4.8	4.4		3.3		2.9	4.6	3.8	3.9
P090	5.1		4.9			2.6		3.2	3.5
P080	4.4	5.1	5.4	3.6		2.1	2.7	4.7	4.2
P070						1.3		1.9	1.7
P060	2.6	4.0				1.0		2.2	2.4
P050								3.0	3.0
P040						2.5			2.5
P030	4.4					3.8	2.3	8.0	5.3
P020	5.5			4.6		3.8	2.4	3.3	3.8
P010						2.7	4.0	3.0	3.0
P000						2.6	3.3		2.9
M010	4.1	4.2				3.5		3.7	3.8
M020	4.0	4.6		3.8			5.0	5.9	4.5
M030	3.9	4.2		4.1		1.2		7.2	4.1
M040	4.4			5.2				2.9	4.0
M050	4.0	4.3				2.9	2.7	4.2	3.8
M060	4.3			3.9		2.5	3.3	3.4	3.6
M070		4.7					4.7	2.8	3.8
M080						3.0		3.0	3.0
M090	4.2	4.3	5.6				2.8	3.3	3.9
M100	3.1					4.0		2.8	3.3
M110	5.0							3.8	4.4
M120	4.9					2.8	3.7		4.0
M130	4.1					3.4		4.0	3.8
M140	4.0			4.8		4.8		4.1	4.4
M150		4.3				2.4			3.3
M160		4.6							4.6
M170						4.5			4.5
Average	4.2	4.4	4.3	4.0	3.6	2.9	3.2	3.5	3.6

< 3.0	Tinggi
3 - 4.9	Medium
5 - 6.9	Rendah
7 - 8.9	Sangat Rendah
> 9.0	Kedap

Secondary Permeability Analysis of RMR

In **FIGURE 9**, secondary permeability coefficients calculated by Snow's equation [17] for rocks dominated by andesite and breccia versus RMR revealed a progressive decrease with an increase in RMR. This equation (logK = -0,3004RMR + 15.07) was obtained from the relationship between the two, where the coefficient of determination generated from this graph was 0.7942. The result indicates a strong relationship between secondary permeability and RMR. The greater weight of the groundwater condition, the smaller the RMR class, and the smaller or more impermeable permeability.

In this study, the RMR according to Bieniawski's classification [19] was in the class III to IV. Meanwhile, the permeability value according to [18] was in the medium to high range. Whereas RMR according to the Bieniawski classification [11] was in the class II to III and the permeability value was high [18]. These two studies show different forms of regression but the coefficient of determination is almost the same **(FIGURE 9).**

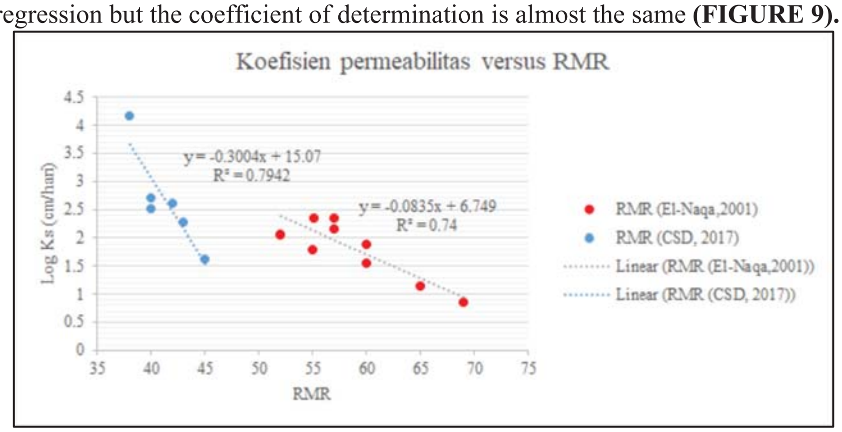

FIGURE 9. Secondary permeability coefficient versus RMR

CONCLUSIONS

Based on the results in this research, it can be concluded as follows:

1. About 66.54% of water sources in the Cibitung block came from groundwater flow, which was 16.37 L/s. In addition, RMR of rock masses around the study area ranges from 32 to 49. The rock masses are in class III (fair rock) and class IV (poor rock).

2. Based on log descriptive statistical analysis, the mean and standard deviation of all data were 1.26 and 3.6, respectively. Log histogram (Ks) on all data proved that the secondary permeability distribution in the underground mine at Cibitung block was heterogeneous.
3. Secondary permeability calculated by Snow's equation has a positive relationship with RMR for rocks dominated by andesite and breccia. The coefficient of determination of both regression analysis is 0.7942.

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